TITLE OF THE INVENTION:

COOLING SYSTEM FOR MOTOR AND COOLING CONTROL METHOD

BACKGROUND OF THE INVENTION:

(Field of the Invention)

The present invention relates to a cooling system for a motor and a cooling control method.

(Prior Art)

An electric vehicle including a hybrid vehicle has a constitution of supplying power to a driving motor from a battery via a power converter and has a forced cooling means for suppressing temperature rise of the power converter and driving motor due to heat generation in correspondence with operations of the power converter and driving motor.

The forced cooling means is structured so as to forced feed a refrigerant such as fresh air or a cooling liquid (an antifreezing solution) to the power converter and driving motor when the temperatures of the power converter and driving motor rise up to a predetermined cooling start temperature, thereby forced cool them.

For example, the inventions described in the patent document 1 (Japanese Application Patent Laid-open Publication No. Hei 07-213091) and the patent document 2 (Japanese Application Patent Laid-open Publication No. Hei 08-33104) are a cooling device for controlling the cooling air speed according to the temperature of heat radiating fins of a semiconductor element of a power converter for controlling an electric

vehicle motor.

Further, the invention described in the patent document 3 (Japanese Application Patent Laid-open Publication No. Hei 10-210790) is an inverter cooling device for an electric vehicle for detecting the temperature of a semiconductor element of an inverter for supplying a current to a motor and controlling the flow rate of a refrigerant according to the temperature of the semiconductor element and the change rate thereof.

Further, in the patent document 4(Japanese Application Patent Laid-open Announcement Publication No. 2001-527612), a cooling device for detecting the temperatures of a temperature control fluid and ambient air to control the temperature of engine oil of a vehicle at a proper temperature is described.

For a driving motor of a driving device for an electric vehicle, a DC commutator motor or an inverter driving type DC non-commutator motor is generally used and the power supply to such a driving motor is controlled by a power converter such as a chopper circuit or an inverter circuit. During the operation (power supply control), in the driving motor, a loss due to flowing of a current through a coil or a mechanical loss during high-speed rotation is caused, and also in the power converter, a loss is caused during power supply to a semiconductor element for power conversion control or at the time of switching, and these losses are finally converted to heat, and the total amount of heat reaches several kW at the maximum.

Such generation of heat causes temperature rise of the driving motor and power converter and when it is left as it is, the driving motor

and power converter cannot prove predetermined performance due to the temperature rise. Furthermore, the insulating material is reduced in the withstand voltage and is destroyed finally, so that generated heat must be removed.

As a forced cooling means which effectively radiates a large amount of heat generated and can be mounted in a limited space, a method for forced flowing a refrigerant using a device such as a pump or a fan and radiating heat by heat exchange between a device generating heat and the refrigerant is general.

The forcible cooling control by a pump or a fan is structured so as to detect the temperatures of the driving motor and power converter, compare them with the forcible cooling start temperature which is set fixedly, and start the operation of the pump or fan when the detected temperatures reach the forcible cooling start temperature.

Under this forcible cooling control, the forcible cooling start temperature is fixed, so that in winter when the air temperature is low, the difference between the temperature at the time of operation start of a driving device for an electric vehicle and the maximum temperature during operation is large.

In the power converter, when the temperature cycle is added to the semiconductor element for power conversion control used for power conversion, thermal stress caused by the difference in the linear expansion coefficient between the members is generated and a thermal fatigue failure is generated. Therefore, to avoid generation of a failure due to thermal stress, it is desirable to avoid an excessive temperature

difference in the temperature cycle. Moreover, it is required to forced cool the semiconductor element for power conversion control so as to maintain it within the heat resistance allowable temperature range before high-temperature failure or limit the amount of heat.

Further, in the driving motor, since the dielectric strength of electrical parts and the magnetic characteristics of magnetic parts are reduced in correspondence with temperature rise, it is desirable to cool these parts so as to prevent the temperature of each of them from exceeding the heat resistance allowable temperature or limit the amount of heat.

Furthermore, when a device such as a pump or a fan is operated, energy consumption is followed by, so that when such a device is activated often, the energy consumption is increased and the energy consumption rate of a vehicle gets worse.

Such a problem is a problem common to not only a cooling system for a driving device for an electric vehicle but also various motors using a driving motor.

SUMMARY OF THE INVENTION:

An object of the present invention is to provide a cooling system for a motor and a cooling control method suited to prevent a thermal stress failure due to the temperature cycle of a power converter for controlling power supply to a driving motor.

Another object of the present invention is to provide a cooling system for a motor and a cooling control method suited to prevent a thermal stress failure due to the temperature cycle of a power converter

and to maintain a driving motor and the power converter within the heat resistance allowable temperature range.

Still another object of the present invention is to provide a cooling system for a motor and a cooling control method suited to prevent a thermal stress failure due to the temperature cycle of a power converter, to maintain a driving motor and the power converter within the heat resistance allowable temperature range, and to reduce the energy consumption for forcible cooling.

The present invention provides a cooling system for a motor comprising a driving motor, a power converter for controlling the driving motor, and a cooling means for forced cooling the driving motor and power converter, wherein: the cooling means has a refrigerant feeding means, a motor temperature detection means for detecting the temperature of the driving motor and outputting a motor temperature detection signal, a power converter temperature detection means for detecting the temperature of the power converter and outputting it as a power converter temperature detection signal, and a forcible cooling control means for referring to the motor temperature detection signal and power converter temperature detection signal and controlling the refrigerant feeding means and the forcible cooling control means has a motor forcible cooling control temperature storage means for storing the motor forcible cooling control temperature for starting or stopping forcible cooling for the driving motor, a power converter operation start temperature storage means for storing the temperature of the power converter at the time of operation start as a power converter operation

start temperature, and a power converter forcible cooling control temperature rise amount storage means for setting and storing the temperatures for starting and stopping forcible cooling for the power converter as a forcible cooling control temperature rise amount by the temperature rise amount from the power converter operation start temperature and refers to the power temperature detection signal and power converter temperature detection signal and when the motor temperature detection signal rises up to the motor forcible cooling control temperature or the temperature rise amount of the power converter temperature detection signal from the power converter operation start temperature reaches the rise amount of the forcible cooling control temperature, starts control of the operation of the refrigerant feeding means.

And, the rise amount of forcible cooling control temperature includes the forcible cooling start temperature and forcible cooling stop temperature and the difference between the forcible cooling start temperature and the forcible cooling stop temperature is fixed.

Further, the forcible cooling control means changes the rise amount of forcible cooling control temperature according to the power converter operation start temperature.

Further, the rise amount of forcible cooling control temperature according to the power converter operation start temperature decreases as the power converter operation start temperature rises.

Further, the forcible cooling start temperature and forcible cooling stop temperature in the rise amount of forcible cooling control temperature

decreasing as the power converter operation start temperature rises reduce the change amount of the forcible cooling stop temperature for the forcible cooling start temperature.

Further, the forcible cooling control means obtains the temperature rise amount from the power converter operation start temperature when the operation is restarted within a short stop period after ending of the operation as a temperature rise from the power converter operation start temperature at the time of preceding operation start.

Further, the refrigerant feeding means has a refrigerant circulation system for circulating a liquid refrigerant by connecting the driving motor, power converter, radiator with a motor fan, and pump in series and the forcible cooling control means has a fresh air temperature detection means for detecting the fresh air temperature and outputting a fresh air temperature detection signal and controls the motor fan according to the temperature difference between the fresh air and the liquid refrigerant.

Further, the forcible cooling control means, when the fresh air temperature or the liquid refrigerant temperature at the time of operation start of the motor is not higher than the solidifying temperature of the liquid refrigerant, sets the power converter operation start temperature to the solidifying temperature of the liquid refrigerant.

Further, the power converter, when the temperature of the driving motor or the power converter approaches the heat resistance allowable temperature, reduces the conversion output power.

Further, the power converter temperature detection means is built in the chip of semiconductor switching element constituting the power

converter.

Further, the present invention provides a cooling system for a motor comprising a driving motor, a power converter for controlling the driving motor, and a cooling means for forced cooling the driving motor and power converter, wherein: the cooling means has a refrigerant feeding means, a motor temperature detection means for detecting the temperature of the driving motor and outputting a motor temperature detection signal, a power converter temperature detection means for detecting the temperature of the power converter and outputting it as a power converter temperature detection signal, and a forcible cooling control means for referring to the motor temperature detection signal and power converter temperature detection signal and controlling the refrigerant feeding means and the forcible cooling control means has a fresh air temperature detection means for detecting the fresh air temperature and outputting a fresh air temperature detection signal, and refers to the motor temperature detection signal, power converter temperature detection signal, and fresh air temperature detection signal, thereby controls the refrigerant feeding means.

Further, the present invention provides a cooling control method for a motor comprising a driving motor, a power converter for controlling the driving motor, and a cooling means for forced cooling the driving motor and power converter, wherein: the cooling means has a refrigerant feeding means, a motor temperature detection means for detecting the temperature of the driving motor and outputting a motor temperature detection signal, a power converter temperature detection means for

detecting the temperature of the power converter and outputting it as a power converter temperature detection signal, and a forcible cooling control means for referring to the motor temperature detection signal and power converter temperature detection signal and controlling the refrigerant feeding means and the forcible cooling control means stores the motor forcible cooling control temperatures for starting and stopping forcible cooling for the driving motor, the temperature of the power converter at the time of operation start as a power converter operation start temperature, and the forcible cooling control temperature rise amount set by the temperature rise amount from the power converter operation start temperature as a temperature for starting or stopping forcible cooling for the power converter and refers to the power temperature detection signal and power converter temperature detection signal and when the motor temperature detection signal rises up to the motor forcible cooling control temperature or the temperature rise amount of the power converter temperature detection signal from the power converter operation start temperature reaches the rise amount of the forcible cooling control temperature, starts control of the operation of the refrigerant feeding means.

BRIEF DESCRIPTION OF THE DRAWINGS:

Fig. 1 is a block diagram of the cooling system for the driving device for an electric vehicle of the first embodiment of the present invention;

Fig. 2 is a forcible cooling characteristic diagram of the first embodiment;

Fig. 3 is a flow chart of the forcible cooling control process of the first embodiment;

Fig. 4 is a forcible cooling control information table of the second embodiment of the present invention;

Fig. 5 is a temperature characteristic diagram showing changes with time of the temperature of the power converter of the third embodiment of the present invention;

Fig. 6 is a block diagram of the cooling system for the driving device for an electric vehicle of the fourth embodiment of the present invention; and

Fig. 7 is a characteristic diagram showing changes with time of the temperature of the liquid refrigerant (the power converter) of the cooling system for the driving device for an electric vehicle of the fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION:

The embodiments of the present invention will be explained with reference to Figs. 1 to 6. Further, the common or equivalent constituent parts in the respective embodiments are given the same numerals and duplicated explanation will be omitted.

The first embodiment of the present invention will be explained by referring to Figs. 1 and 2. Fig. 1 is a block diagram of the cooling system for the driving device for an electric vehicle of the first embodiment, and Fig. 2 is a forcible cooling characteristic diagram thereof, and Fig. 3 is a flow chart of the forcible cooling control process.

The first embodiment basically has a constitution that for forcible cooling for the power converter, the temperature of the power converter at the time of operation start of an electric vehicle (when the key switch is turned on or the power converter starts operation) is stored as a power converter operation start temperature, and the temperature rise amount of the power converter from the power converter operation start temperature is monitored, and the forcible cooling control is started and for forcible cooling for the driving motor, the temperature of the driving motor is monitored and when the temperature rises up to the forcible cooling start temperature set on the basis of the heat resistance allowable temperature of the driving motor, the forcible cooling control is started. Further, the first embodiment has a constitution that even under such forcible cooling control, when the temperature of the driving motor or the power converter approaches the heat resistance allowable temperature, the conversion output power is reduced.

The constitution of the cooling system for the driving device for an electric vehicle will be explained by referring to Fig. 1. The cooling system for the driving device for an electric vehicle has a driving motor 1 such as an inverter driving brushless motor or a commutator motor for generating running power of an electric vehicle, a motor temperature detection sensor 2 which is a motor temperature detection means for detecting the temperature of the driving motor 1 and outputting a motor temperature detection signal, a power converter 3 such as an inverter or a chopper for controlling conversion output power for operating the driving motor 1, a power converter temperature detection sensor 4 which is a

power converter temperature detection means for detecting the temperature of the power converter 3 and outputting a power converter temperature detection signal, a forced cooling motor fan 6 for taking in fresh air 5 and sending it as a forced cooling refrigerant, a forced cooling refrigerant flow path 7 for transferring the forced cooling refrigerant sent from the forced cooling motor fan 6 to the power converter 2 and the driving motor 1, a main control unit 10 for referring to an instruction signal output from a key switch 8 or an acceleropedal 9, a motor temperature detection signal output from the motor temperature detection sensor 2, or a power converter temperature detection signal output from the power converter temperature detection sensor 4, thereby controlling the power converter 3 and outputting a run-stop signal to a forcible cooling control unit which will be described later, a forcible cooling control unit 11 for referring to the motor temperature detection signal output from the motor temperature detection sensor 2, the power converter temperature detection signal output from the power converter temperature detection sensor 4, and the run-stop signal output from the main control unit 10, thereby controlling the operation of the forced cooling motor fan 6, and a battery 12 for supplying DC power to them.

The power converter 3, although detailed diagramatic explanation is omitted, has a structure that a power control electronic circuit unit 303 composed of an inverter or a chopper formed on an insulating substrate 302 made of aluminum nitride using a semiconductor switching element 301 such as IGBT is joined to a cooling substrate 304 made of copper or aluminum, which is exposed to a refrigerant and radiates heat, by

soldering 305 and the power control electronic circuit unit 303 operates so as to control the conversion output power supplied to the driving motor 1 from the battery 12 on the basis of a control signal from the main control unit 10. And, heat generated in the power control electronic circuit unit 303 in correspondence with the power conversion-supply control operation is radiated to a refrigerant flowing through the forced cooling refrigerant flow path 7 via the soldering 305 and the cooling substrate 304. The power converter temperature detection sensor 4 is attached onto the insulating substrate 302 so as to be sensitive to the temperature of the insulating substrate 302.

The main control unit 10, although detailed diagramatic explanation is omitted, is mainly composed of a microcomputer composed of a CPU 1001, a memory 1002, and an input-output circuit 1003. The memory 1002 stores beforehand an operation control program and control information for reducing the conversion output power in order to reduce the amount of heat so as to maintain the driving motor 1 and the power converter 3 within the heat resistance allowable range or to reduce it to zero (for example, the temperature of about 90% of the heat resistance allowable temperature is set as a conversion output power reduction start temperature and the heat resistance allowable temperature is set as a conversion output stop temperature).

The CPU 1001 has an operation control function for executing the operation control program stored in the memory 1002 when the key switch 8 is turned on (a run instruction), thereby entering the operation control state, switching the run-stop signal to be output to the forcible cooling

control unit 11 to "Run", controlling the power converter 3, on the basis of a speed instruction signal according to the working amount of the acceleropedal 9, so as to supply the conversion output power according to the speed instruction signal to the driving motor 1, further monitoring the motor temperature detection signal output from the motor temperature detection sensor 2 and the power converter temperature detection signal output from the power converter temperature detection sensor 4, reducing the conversion output power in order to reduce the amount of heat so as to maintain the driving motor 1 and the power converter 3 within the heat resistance temperature range, controlling the power converter 3 so as to reduce the conversion output power to zero because the speed instruction signal becomes zero when the acceleropedal is released, and further switching the run-stop signal to be output to the forcible cooling control unit 11 to "Stop" when the key switch 8 is turned off (a stop instruction) and putting the cooling system into the operation control end (stop) state.

The forcible cooling control unit 11, although detailed diagramatic explanation is omitted, is mainly composed of a microcomputer composed of a CPU 1101, a memory 1102, and an input-output circuit 1103. The memory 1102 stores beforehand the forcible cooling control program and as control information, motor forcible cooling control temperatures Tm1 and Tm2 for starting or stopping forcible cooling for the driving motor 1 and forcible cooling control temperature rise amounts $Ti\alpha$ and $Ti\beta$ that the temperature for starting or stopping forcible cooling for the power converter 3 is set by the temperature rise amount from the power converter operation start temperature Tis.

In consideration of that the motor forcible cooling control temperatures Tm1 and Tm2 for forcible cooling for the driving motor 1 prevent the dielectric strength of the electrical parts constituting the driving motor 1 and the magnetic characteristics of the magnetic parts from reducing in correspondence with temperature rise and reduce the forcible cooling consumption power (energy consumption) by operating the forced cooling motor fan 6, the forcible cooling start temperature Tm1 for starting forcible cooling and the forcible cooling stop temperature Tm2 for stopping forcible cooling are set. For example, the forcible cooling start temperature Tm1 is set to 90°C and the forcible cooling stop temperature Tm2 is set to 70°C.

The forcible cooling control temperature rise amounts Tiα and Tiβ for forcible cooling for the power converter 3 are the forcible cooling start temperature rise amount Tiα for starting forcible cooling and the forcible cooling stop temperature rise amount Tiβ for stopping forcible cooling, and they are temperature rise amounts mainly set in consideration of that the soldering 305 adhering the power control electronic circuit unit 303 to the cooling substrate 304 is prevented from failure due to thermal stress by the temperature cycle of the power converter 3 and the forcible cooling consumption power (energy consumption) is reduced by operating the forced cooling motor fan 6, and as shown in Fig. 2, the forcible cooling start temperature rise amounts Tiα is set by the temperature rise amount from the power converter operation start temperature Tiβ, and the forcible cooling stop temperature rise amount Tiβ is set by the temperature rise amount from the power converter operation start temperature Tis. For

example, the forcible cooling start temperature rise amounts Tiα is set to 50°C and the forcible cooling stop temperature rise amount Tiβ is set 35°C. The difference Tiγ between the forcible cooling start temperature rise amounts Tiα and the forcible cooling stop temperature rise amount Tiβ is fixed (here 15°C), so that the forcible cooling stop temperature rise amount Tiβ may be set by the lowering amount (= difference Tiγ) from the forcible cooling start temperature rise amounts Tiα.

The CPU 1101 executes the forcible cooling control program when the run-stop signal output from the main control unit 10 is switched to "Run" and stores the power converter temperature detection signal (Ti) output from the power converter temperature detection sensor 4 in the memory 1102 as a power converter operation start temperature Tis. Thereafter, the CPU 1101 reads the motor temperature detection signal (Tm) output from the motor temperature detection sensor 2 and the power converter temperature detection signal (Ti) output from the power converter temperature detection sensor 4 whenever necessary and executes the forcible cooling control.

The CPU 1101, under the forcible cooling control for forcible cooling for the driving motor 1, monitors the motor temperature detection signal (Tm) output from the motor temperature detection sensor 2, when the motor temperature Tm rises up to or higher than the motor forcible cooling start temperature Tm1 for starting forcible cooling for the driving motor 1, operates the forced cooling fan 6, takes in fresh air 5, sends it to the forced cooling refrigerant flow path 7 as a forced cooling refrigerant, and forced cools the driving motor 1 and the power converter 3. And, by this

forcible cooling, when the temperature Tm of the driving motor 1 lowers down to or lower than the motor forcible cooling stop temperature Tm2, the CPU 1101 stops the forced cooling fan 6 and stops the forcible cooling.

Further, under the forcible cooling control for the power converter 3, when the temperature Ti of the power converter 3 rises up to or higher than the power converter forcible cooling start temperature (Tis + Tiα) that the forcible cooling start temperature rise amount Tiα is added to the power converter operation start temperature Tis, the CPU 1101 operates the forced cooling fan 6, takes in fresh air 5, sends it to the forced cooling refrigerant flow path 7 as a forced cooling refrigerant, and forced cools the driving motor 1 and the power converter 3. By this forcible cooling, when the temperature Tiβ of the power converter 3 lowers down to or lower than the power converter forcible cooling stop temperature (Tis + Tiβ) that the forcible cooling stop temperature rise amount Tis is added to the power converter operation start temperature Tis, the CPU 1101 stops the forced cooling fan 6 and stops the forcible cooling.

The forcible cooling for the driving motor 1 and the forcible cooling for the power converter 3 are structured so as to share the forced cooling motor fan 6, so that when the forcible cooling of either of the driving motor 1 and the power converter 3 is necessary, the CPU 1101 operates the forced cooling motor fan 6 and controls so as to send the forced cooling refrigerant to the forced cooling refrigerant flow path 7.

An example of the control process executed by the CPU 1101 of the forcible cooling control unit 11 in order to realize such forcible cooling control will be explained by referring to the control process flow chart

shown in Fig. 3.

Step S1:

The CPU1101 monitors the run-stop signal output from the main control unit 10 and when the signal is switched to "Run", goes to Step S2.

Step S2:

When the run-stop signal is switched to "Run", the CPU 1101 reads the power converter temperature detection signal output from the power converter temperature detection sensor 4, stores the power converter temperature Ti in the memory 1102 as a power converter operation start temperature Tis, and goes to Step S3.

Step S3:

The CPU 1101 obtains the power converter forcible cooling start temperature ($Tis + Ti\alpha$) that the forcible cooling start temperature rise amount $Ti\alpha$ is added to the power converter operation start temperature Tis and the power converter forcible cooling stop temperature ($Tis + Ti\beta$) that the forcible cooling stop temperature rise amount $Ti\beta$ is added to the power converter operation start temperature Tis, stores (sets) them in the memory 1102, and goes to Step S4.

Step S4:

The CPU 1101 reads the motor temperature detection signal (Tm) and the power converter temperature detection signal (Ti), detects the motor temperature Tm and the power converter temperature Ti, and goes to Step S5.

Step S5:

The CPU 1101 compares the detected motor temperature Tm with

the motor forcible cooling start temperature Tm1 stored in the memory 1102 and branches the process. When the motor temperature Tm is not lower than the motor forcible cooling start temperature Tm1, the CPU 1101 goes to Step S6 and when the motor temperature Tm is lower than the motor forcible cooling start temperature Tm1, the CPU 1101 goes to Step S7.

Step S6:

The CPU 1101 puts the forced cooling motor fan 6 into the operation (rotation) state and goes to Step S12.

Step S7:

The CPU 1101 compares the detected power converter temperature Ti with the power converter forcible cooling start temperature ($Tis + Ti\alpha$) stored in the memory 1102 and branches the process. When the power converter temperature Ti is not lower than the power converter forcible cooling start temperature ($Tis + Ti\alpha$), the CPU 1101 goes to Step S6 and when the power converter temperature Ti is lower than the power converter forcible cooling start temperature ($Tis + Ti\alpha$), the CPU 1101 goes to Step S8.

Step S8:

The CPU 1101 confirms whether the forced cooling motor fan 6 is in operation or not and when it is in operation, goes to Step S9, otherwise goes to Step S12.

Step S9:

The CPU 1101 compares the detected motor temperature Tm with the motor forcible cooling stop temperature Tm2 stored in the memory

1102, when the motor temperature Tm is higher than the motor forcible cooling stop temperature Tm2, goes to Step S12, and when the motor temperature Tm is not higher than the motor forcible cooling stop temperature Tm2, goes to Step S10.

Step S10:

The CPU 1101 compares the detected power converter temperature Ti with the power converter forcible cooling stop temperature (Tis + Tiβ) stored in the memory 1102, when the power converter temperature Ti is higher than the power converter forcible cooling stop temperature (Tis + Tiβ), goes to Step S12, and when the power converter temperature Ti is not higher than the power converter forcible cooling stop temperature (Tis + Tiβ), the CPU 1101 goes to Step S11.

Step 11:

The CPU 1101 puts the forced cooling motor fan 6 into the rotation stop state and goes to Step S12.

Step 12:

The CPU 1101 confirms the run-stop signal output from the main control unit 10 and branches the process. When the run-stop signal is switched to "Run", the CPU 1101 goes to Step S4 and when it is switched to "Stop", goes to Step S13.

Step S13:

The CPU 1101 executes the operation end process of putting the forced cooling motor fan 6 into the stop state and finishes the operation.

According to such forcible cooling control, the forcible cooling for the power converter 3 is controlled on the basis of the temperature rise

amount from the power converter operation start temperature set in consideration of that the power converter 3 is prevented from failure by thermal stress due to the temperature cycle and the forcible cooling power consumption is reduced by operating the forced cooling motor fan 6, so that the temperature difference is small even in winter when the temperature at the time of operation start is low and the temperature cycle can be kept constant through all seasons, thus thermal stress can be prevented from excessively increasing and the forcible cooling power consumption is reduced. Further, the forcible cooling for the driving motor 1 is controlled on the basis of the forcible cooling control temperature set in consideration of that the dielectric strength of the electrical parts constituting the driving motor 1 and the magnetic characteristics of the magnetic parts are prevented from reducing in correspondence with temperature rise and the forcible cooling consumption power is reduced by operating the forced cooling motor fan 6, so that the performance and life of the driving motor 1 are prevented from degradation and the forcible cooling power consumption is reduced.

In this embodiment, as a forced cooling refrigerant, fresh air 5 is used. However, the present invention is not limited to it.

Further, for the forcible cooling control, two stages of control of "forcible cooling operation" and "stop" are illustrated. However it may be changed to multi-stage control that the forcible cooling force (the rotational speed of the forced cooling fan 6) is changed according to the temperature.

The second embodiment of the present invention will be explained

by referring to Figs. 1 to 4. Fig. 4 is a forcible cooling control information table of the second embodiment.

The second embodiment has a constitution that the forcible cooling start temperature rise amount Tiα for starting forcible cooling which is a forcible cooling control temperature rise amount in forcible cooling for the power converter 3 and the forcible cooling stop temperature rise amount Tis for stopping forcible cooling in the forcible cooling control characteristics shown in Fig. 2 in the first embodiment mentioned above are set by variables changing according to the power converter operation start temperature Tis. Concretely, when the power converter operation start temperature Tis rises, the forcible cooling start temperature rise amount Tiα and the forcible cooling stop temperature rise amount Tis are reduced. The reduction amount of the forcible cooling stop temperature rise amount Tis due to rising of the power converter operation start temperature Tiβ is smaller than the reduction amount of the forcible cooling start temperature rise amount Tiα. Fig. 4 illustrates the forcible cooling start temperature rise amount Tiα and the forcible cooling stop temperature rise amount Tis for this power converter operation start temperature Tiβ.

And, when forcible cooling control for a cooling system for a driving device for an electric vehicle structured as the block diagram shown in Fig. 1 is executed on the basis of such control information, although the thermal stress acting on the power converter 3 increases, the operation of the forced cooling motor fan 6 at low temperature is suppressed, so that the power consumption for forcible cooling can be reduced more.

Concretely, in the control of the second embodiment, a process is added that to obtain and set the power converter forcible cooling start temperature (Tis + Tiα) and the power converter forcible cooling stop temperature (Tis + Tiβ) at Step S3, the CPU 1101 of the forcible cooling control unit 11 selects the forcible cooling start temperature rise amount Tiα and the forcible cooling stop temperature rise amount Tiβ to be added to the power converter operation start temperature Tis according to the power converter operation start temperature Tis.

The third embodiment of the present invention will be explained by referring to Figs. 1 to 5. Fig. 5 is a temperature characteristic diagram showing changes with time of the temperature of the power converter of the third embodiment.

During the stop period after operation end, the temperatures of the driving motor 1 and the power converter 3 slowly lower due to natural cooling. Therefore, when the operation is restarted within a short period after operation end, the temperatures of the driving motor 1 and the power converter 3 are considerably higher than the environmental temperature and thermal stress remains in the power converter 3. The thermal stress of the power converter 3 in correspondence with temperature rise due to restart of the operation in such a state is desirably considered to be caused by the temperature rise from the power converter operation start temperature at the time of preceding operation start which is operation start after a long stop period causing disappearing of thermal stress.

The third embodiment, in consideration of such residual thermal stress of the power converter 3, as the aforementioned power converter

operation start temperature Tis in the first embodiment, adopts the power converter operation start temperature at the time of preceding operation start which is operation start after a long stop period causing disappearing of thermal stress when the operation is restarted within a short stop period after operation end.

Concretely, as shown in Fig. 5, when the operation is started by turning on the key switch 8 at the time t1 when an electric vehicle is stopped for many hours and the temperature Ti of the power converter 3 approaches the environmental temperature, the power converter operation start temperature at that time is Tis1, and thereafter, by repetitive running and stopping of the electric vehicle, the temperatures Tm and Ti of the driving motor 1 and the power converter 3 rise and lower repeatedly, and when the temperature Tm or Ti of the driving motor 1 or the power converter 3 becomes the motor forcible cooling start temperature Tm1 or the power converter forcible cooling start temperature (Tis + Tiα) or higher, the forced cooling motor fan 6 is operated and the driving motor 1 and the power converter 3 are started to be forced cooled, and when the temperature Tm or Ti of the driving motor 1 or the power converter 3 becomes the motor forcible cooling stop temperature Tm2 or the power converter forcible cooling stop temperature (Tis + Tiβ) or lower, the forced cooling motor fan 6 is stopped and the forcible cooling is stopped.

When the key switch 8 is turned off at the time t2, and the operation is finished, and the system enters the stop state, the temperatures Tm and Ti of the driving motor 1 and the power converter 3 lower due to

natural heat radiation.

Thereafter, when the operation is restarted at the time t3 when the temperature Ti of the power converter 3 is higher than the environmental temperature, the power converter operation start temperature at this time is Tis2. In this state, in the power converter 3, the thermal stress due to temperature rise by heat generation at the time of preceding operation remains and when the power converter forcible cooling start temperature (Tis + Tiα) and the power converter forcible cooling stop temperature (Tis + Tiβ) are set by adding the forcible cooling start temperature rise amount Tiα and the forcible cooling stop temperature rise amount Tis to the power converter operation start temperature Tis2, there is the possibility that the forcible cooling control temperature for the power converter 3 may become excessively high.

Therefore, the third embodiment is structured so that in a case of operation restart after such an operation stop for a short time, the temperature of the power converter 3 lowers sufficiently and the power converter operation start temperature Tis1 at the time of preceding operation start which is operation start after a long stop period causing disappearing of thermal stress is adopted as the power converter operation start temperature Tis for setting the power converter forcible cooling start temperature (Tis + Tiα) and the power converter forcible cooling stop temperature (Tis + Tiα) to be used for forcible cooling control for the power converter 3.

To realize this forcible cooling control, the CPU 1101 of the forcible cooling control unit 11 of the third embodiment has a clock function and

the memory 1102 has an information holding function for storing and holding a desired stop period preset in consideration of the time necessary for sufficient lowering of the temperature of the power converter 3 and holding the power converter operation start temperature Tis even during stop. And, the CPU 1101, in the operation ending operation at Step S13, performs a process of storing and holding the operation end date and time in the memory 1102, at Step S2, reads the operation start date and time and obtains the stop period from the previous operation end date and time, when the stop period is longer than the desired stop period, rewrites and sets the temperature Tis2 of the power converter 3 at that time with the power converter operation start temperature Tis, and when the stop period is within the desired stop period, sets the time Tis1 of the power converter 3 at the time of previous start with the power converter operation start temperature Tis.

The others are the same as those of the aforementioned embodiments.

According to the third embodiment aforementioned, the same forcible cooling effect as that of the aforementioned embodiments is obtained, and even when the operation is restarted after short-time stop, the temperature difference in the power converter 3 is not large and the temperature cycle can be controlled within a fixed range, so that a highly reliable driving device for an electric vehicle can be realized.

The fourth embodiment of the present invention will be explained by referring to Figs. 2 to 6. Fig. 6 is a block diagram of the cooling system of the driving device for an electric vehicle of the fourth embodiment.

The fourth embodiment has a structure that heat of the power converter 3 and the driving motor 1 is radiated by a liquid refrigerant and heat of the liquid refrigerant is radiated to fresh air by a radiator with a motor fan and the heat radiation capacity (operation and stop of the motor fan) of the radiator with a motor fan to fresh air is controlled. Namely, in a state that a liquid refrigerant is circulated and the units are forced cooled, when the temperature difference between the liquid refrigerant and fresh air is large, heat is radiated by natural ventilation because the radiation capacity of the radiator is large and when the temperature difference between the liquid refrigerant and fresh air is small, heat radiation is promoted by forcible ventilation because the radiation capacity of the radiator is small.

In the fourth embodiment, as a refrigerant circulation system for circulating a refrigerant, a forced cooling refrigerant flow path 7 of coming out from a water pump 13, sequentially passing the power converter 3, the driving motor 1, and a radiator 14 with a motor fan for radiating heat to fresh air 5, and returning to the water pump 13 is formed. Further, a fresh air temperature detection sensor 15 which is a fresh air temperature detection means for detecting the temperature of fresh air 5 and outputting a fresh air temperature detection signal (Ta) is provided.

And, the forcible cooling control unit 11 controls the water pump 13 in the same way as with control for the forced cooling motor fan 6, when the water pump 13 is operated, and a refrigerant is circulated so as to execute forcible cooling, refers to the fresh air temperature detection signal (Ta) output from the fresh air detection sensor 15, when the

temperature difference Ta-f between the fresh air temperature Ta and the liquid refrigerant temperature Tf becomes the preset radiator forcible heat radiation start temperature difference Tw1 or smaller, operates the motor fan of the radiator 14 so as to generate forcible ventilation, and when the temperature difference becomes the radiator forcible heat radiation stop temperature difference Tw2 or larger, executes the control for stopping the motor fan. The temperature difference Ta-f (the radiator forcible heat radiation start temperature difference Tw1 and the radiator forcible heat radiation stop temperature difference Tw2) is set according to the heat radiation characteristics of the radiator 14 with a motor fan.

The liquid refrigerant temperature Tf is desirably detected by installing a temperature detection sensor in the forced cooling refrigerant flow path 7. However, in the fourth embodiment, there is a relationship that the liquid refrigerant temperature Tf and the power converter temperature Ti are almost constant, so that the power converter temperature detection signal (Ti) is appropriated. Further, the system may be structured so as to appropriate a motor temperature detection signal (Tm) or to install a temperature detection sensor (not shown in the drawing) in the radiator 14 with a motor fan and appropriate a temperature detection signal output from the temperature detection sensor.

Since the operation of the motor fan of the radiator 14 with a motor fan is controlled like this, the system is structured so that the forcible cooling control unit 11 presets and stores the radiator forcible heat radiation start temperature difference Tw1 and the radiator forcible heat radiation stop temperature difference Tw2 in the memory 1102 and the

CPU 1101, when the water pump 13 is operated and a refrigerant is circulated so as to execute forcible cooling, refers to a fresh air temperature detection signal output from the fresh air detection sensor 15, detects a fresh air temperature Ta, when the temperature difference Ta-f between the fresh air temperature Ta and the liquid refrigerant temperature Tf becomes a preset radiator forcible heat radiation start temperature Tw1 or higher, operates the motor fan of the radiator 14, and when the temperature difference becomes the radiator forcible heat radiation stop temperature Tw2 or lower, executes the control process of stopping the motor fan.

The others are the same as those of the aforementioned embodiments.

According to the fourth embodiment aforementioned, the same forcible cooling effect as that of the aforementioned embodiments is obtained, and the driving motor 1 and the power converter 3 can be forced cooled by a liquid refrigerant having large heat capacity, so that the cooling efficiency is increased and the system can be made compact. Further, the radiator 14 with a motor fan radiates heat naturally with the motor fan stopped until the temperature difference becomes the radiator forcible heat radiation start temperature difference Tw1 or larger, so that the power (energy) consumption for operating the motor fan and generating forcible ventilation can be reduced.

The fifth embodiment of the present invention will be explained by referring to Figs. 2 to 7. Fig. 7 is a characteristic diagram showing changes with time of the temperature of the liquid refrigerant (the power

converter) of the cooling system of the driving device for an electric vehicle of the fifth embodiment.

For a liquid refrigerant to be used for forcible cooling, a liquid refrigerant having a solidifying temperature lower than an expectable fresh air temperature in an environment that an electric vehicle is used is used. However, the fresh air temperature may become lower than the solidifying temperature of the liquid refrigerant due to coming of unexpected cold. In such a case, the liquid refrigerant is solidified. However, since the electric vehicle is driven, the liquid refrigerant is heated and melted by heat generated by the driving motor and power converter. However, when the forcible cooling control system is functioned in this state and the water pump and radiator with a motor fan are operated, there is the possibility that the liquid refrigerant may be over-cooled and re-solidified.

The fifth embodiment is structured so as to prevent such re-solidification of a liquid refrigerant and when the temperature of a liquid refrigerant or fresh air at the time of operation start of an electric vehicle is not higher than the solidifying temperature of the liquid refrigerant, to use the liquid refrigerant solidifying temperature as a power converter operation start temperature Tis set for forcible cooling control.

Concretely, as shown in Fig. 7, under the forcible cooling control in the state that the power converter operation start temperature Tis3 corresponding to the temperature of fresh air or the temperature of a liquid refrigerant is not higher than the solidifying temperature Tfm of a refrigerant flowing in the forced cooling liquid refrigerant flow path 7, the solidifying temperature Tfm is set as a power converter operation start

temperature Tis and the forcible cooling control process is executed.

By doing this, the forcible cooling system is operated at a considerably higher temperature than the solidifying temperature Tfm of the liquid refrigerant, so that the liquid refrigerant can be prevented from re-solidification and the power consumption can be reduced.

In the embodiments explained above, the control and forcible cooling control for the driving motor 1 are structured so as to be executed separately by the main control unit 10 and the forcible cooling control unit 11. However, the control and forcible cooling control for the driving motor 1 may be structured so as to be executed by one main control unit 10.

The power converter temperature detection sensor 4 of the respective embodiments explained above is attached onto the insulating substrate 302 of the power control electronic circuit unit 303 of the power converter 3. However, when a temperature detection sensor is built in the chip of the semiconductor switching element 301 such as IGBT, the temperature detection sensor built in the chip may be substituted.

Further, the present invention is not limited to the cooling system and cooling control method for the driving device for an electric vehicle mentioned above and can be used as a cooling system and a cooling control method for various motors comprising a driving motor, a power converter for controlling the driving motor, and a cooling means for forced cooling the driving motor and power converter, wherein the cooling means has a refrigerant feeding means, a motor temperature detection means for detecting the temperature of the driving motor and outputting a motor

temperature detection signal, a power converter temperature detection means for detecting the temperature of the power converter and outputting it as a power converter temperature detection signal, and a forcible cooling control means for referring to the motor temperature detection signal and power converter temperature detection signal and controlling the refrigerant feeding means.

According to the cooling system and cooling control method for a motor of the present invention, the power converter is forced cooled so as to keep the difference between the temperature thereof at the time of operation start and the temperature thereof during operation constant, so that the power converter can be prevented from failure due to thermal stress.

Further, the driving motor and power converter can be maintained within the heat resistance allowable temperature range.

Furthermore, due to forcible cooling, the energy consumption can be reduced.